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EXPERIMENTAL INVESTIGATION OF DISCRETE HEAT TRANSFER MEASUREMENT TECHNIQUES FOR TUNNEL A APPLICATIONS

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Calspan Field Services, Inc.

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AIR FORCE SYSTEMS COMMAND
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Experimental heat transfer tests were conducted to evaluate several testing and data reduction techniques that had potential for improving the quality of heat transfer data obtained in Tunnel A. The wedge used in this investigation was instrumented with several types of heat gages and two thin-skin sections. Data were gathered in an interference flow field by mounting a disturbance generator on the surface of the wedge. Tests were conducted at Mach 3 and free-stream Reynolds number of 3.8×10^6 ft^{-1}. Wedge angles varied from 0 to 25 deg.

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NOMENCLATURE

AO	Intercept of linear curve fit, see Eq. (9)
A1	Slope of linear curve fit, see Eq. (9)
ALPHA	Angle of attack, deg
ALPI	Indicated pitch angle, deg
ALPPB	Prebend angle, deg
b	Thin skin thickness, in.
c	Model material specific heat, Btu/lbm-°R
C1	Gardon gage calibration factor measured at 530°R, Btu/ft^2-sec/mv
C2	Temperature corrected Gardon gage calibration factor, Btu/ft^2-sec/mv. [see Eq. (3)]
DTW/DT	Derivative of the model wall temperature with respect to time, °R/sec
E	Gardon gage output, mv
GAGE	Gage identification number
H(TAW)	Heat transfer coefficient based on TAW for gage data and based on TRT for thin skin data, QDOT/(TAW-TW), Btu/ft^2-sec-°R
H(TT)	Heat transfer coefficient based on TT, QDOT/(TT-TW), Btu/ft^2-sec-°R (see Eq. 1)
HWEDGE, h_w	Calculated heat transfer coefficient, Btu/ft^2-sec-°R (see Appendix III)
KG	Gardon gage temperature calibration factor, °R/mv
M	Free-stream Mach number

MU	Dynamic viscosity based on free-stream temperature, lbf-sec/ft^2
P	Free-stream static pressure, psia
PHII	Indicated roll angle, deg
PREF	Pressure transducer reference pressure, microns
PT	Tunnel stilling chamber pressure, psia
PT2	Total pressure downstream of a normal shock wave, psia
Q	Free-stream dynamic pressure, psia
QDOT	Heat transfer rate, Btu/ft^2-sec
RE	Free-stream unit Reynolds number, ft^{-1}
RHO	Free-stream density, lbm/ft^3
RUN	Data set identification number
SHOCK	Disturbance generator indicator; value of 99 indicates shock generator off; value of 05 indicates shock generator on, inclined 5° to flow
t	Time, sec
T	Free-stream static temperature, °R
TAW	Adiabatic wall temperature, °R
T/C	Thermocouple identification number
TGE	Gardon gage edge temperature, °R
TGDEL	Temperature differential across the Gardon gage disc, °R
TRT	Calculated recovery temperature, °R (see Appendix III)
TT	Tunnel stilling chamber temperature, °R
TW	Model surface temperature, °R
V	Free-stream velocity, ft/sec
WEDGE SURFACE ANGLE, θ_w	Wedge surface angle derived from shadowgraph photos, deg

X, Y	Orthogonal body axis system directions (see Table 3)
ρ	Model material density, lbm/ft^3

SUBSCRIPT

i	Conditions at initial time (start of injection sequence)
e	Conditions at the edge of the wedge boundary layer

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 68507F, Control Number 9T03-00-0, at the request of AEDC/DOFO. The AEDC project monitor was Lt. Larry Davis. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The tests were conducted in the von Karman Gas Dynamics Facility (VKF), under AEDC Project No. C110VA.

The primary objective of this project was to gather experimental heat transfer data in Supersonic Wind Tunnel (A) to evaluate several testing and data reduction techniques that had potential for improving the quality of Tunnel A heat transfer data. A wedge surface plate was built to fit on existing support hardware for use in this investigation. The surface plate was instrumented with 41 heat flux gages and 54 thermocouples in two thin-skin sections.

Data were obtained at Mach number 3.0 and a free-stream Reynolds number of 3.8×10^6 ft^{-1}. Wedge surface angle ranged from 0 to 25 deg. Several runs were made with a disturbance generator in place to check instrumentation and data reduction performance in an interference flow-field environment.

Inquiries to obtain copies of the test data should be directed to AEDC/DOS, Arnold Air Force Station, Tennessee 37389. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel A (Fig. 1) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel can be operated at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 750°R at Mach number 6. Minimum operating pressures range from about one-tenth to one-twentieth of the maximum at each Mach number. The tunnel is equipped with a model injection system which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel and airflow calibration information may be found in Ref. 1.

2.2 TEST ARTICLE

Figure 2 presents a photograph of the wedge used during this entry. A sketch of the wedge and the instrumentation locations is shown in Fig. 3. The base is the "Tunnel C Pressure Wedge." A new surface plate was fabricated for this project which incorporated the following:

1. a 3-in. by 1.5-in. by 0.052-in. thin-skin section

2. a 3-in. by 1.5-in. by 0.030-in. thin-skin section

3. locations for 41 heat gages (37 - 1/4-in.-diam gages and 4 1/8-in.-diam gages)

4. a shock generator which could be positioned at angles of 0, 5, 10, and 15 deg.

The surface plate is 17-4 stainless steel and the shock generator is 304 stainless steel. The attachment of the surface plate to the base was designed to minimize air leakage to the back side of the instrumented region of the plate, thereby reducing measurement errors due to cooling or heating of the nonaerodynamic side of the plate.

Prior to testing, the thickness of each thin-skin section was checked using the ultrasonic device in the VKF. It was found that the forward section was uniformly 0.052-in. thick, but that the aft section was 0.027-in. thick with a slight rim around the edge of the section where the thickness was found to be 0.030 in. The wall thicknesses used for data reduction reflected these measurements.

A sketch of the installation in Tunnel A is shown in Fig. 4. The wedge surface was installed with a 12-deg prebend angle.

2.3 TEST INSTRUMENTATION

The instrumentation, recording devices, and calibration methods used to measure the primary tunnel and test data parameters are listed in Table 1a, along with the estimated measurement uncertainties. The range and estimated uncertainties for primary parameters that were calculated from the measured parameters are listed in Table 1b.

The location of instrumentation on the surface plate is shown in Fig. 3b. Instrumentation included:

3 - 1/4-in. Schmidt Boelter Heat Transfer Gages
30 - 1/4-in. Thermopile Gardon Gages (10-mil foil thickness)
4 - 1/4-in. Thermopile Gardon Gages (2-mil foil thickness)
4 - 1/8-in. Thermopile Gardon Gages (5-mil foil thickness)
22 - FeCN Thermocouples in the 0.052-in. section
32 - FeCN Thermocouples in the 0.030-in. section

All thermocouples (both gages and thin-skin) were monitored with the Beckman system. Unfortunately, only 35 of the 41 gage outputs could be monitored with existing instrumentation systems, necessitating use of a plug arrangement. The plugs allowed measurement of all gage outputs at one time or another, but never all 41 together. Two plugs were arranged as follows:

Gages on Plug #1 - 4, 7, 15, 18, 23, 31
Gages on Plug #2 - 3, 5, 20, 33, 34, 41

Since most of the gages on plug #2 are covered when the shock generator is on the model, plug #2 was used when the shock generator was off and plug #1 was used when it was on.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

The nominal test condition for this test is given below:

M	PT, psia	TT, °R	Q, psia	P, psia	RE x 10^{-6}, ft^{-1}
3.0	36	700	6.2	0.98	3.8

A test summary showing the configurations tested and the variables for each is presented in Table 2.

3.2 TEST PROCEDURE

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airstream. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. A given injection cycle is termed a run, and all the data obtained are identified in the data tabulations by a run number.

The test procedure was as follows:

1. Cool model with vortex manifold.
2. Stop cooling and wait for "isothermal" conditions as judged from CRT display.
3. Inject the model and obtain data at 0.068 sec per loop for 20-25 sec (thin-skin).
4. Stop data system and restart with 4-sec per loop rate (for optional Gardon gage data). Data were obtained in this mode for up to 5 min.

3.3 DATA REDUCTION

The reduction of thin-skin thermocouple data normally involves only the calorimeter heat balance, which, in coefficient form is

$$H(TT) \doteq \rho bc \; \frac{DTW/DT}{TT-TW} \tag{1}$$

Radiation and conduction losses are neglected in this heat balance, and data reduction simply requires evaluation of DTW/DT from the temperature-time data and determination of model material properties. For the present test, radiation effects were negligible; however, conduction effects were potentially significant in several regions of the model. To permit identification of these regions and improve evaluation of the data, the following procedure was used.

Separation of variables and integration of Eq. (1), assuming constant ρ, b, c and TT yields

$$\frac{H(TT)}{\rho bc} (t-t_i) = \ell n \left(\frac{TT-TW_i}{TT-TW} \right) \qquad (2)$$

Since $H(TT)/\rho bc$ is a constant, plotting $\ell n\ [(TT-TW_i)/(TT-TW)]$ versus time will give a straight line if conduction is negligible. Thus, deviations from a straight line can be interpreted as conduction effects.

The data were evaluated in this manner and, generally, a reasonably linear portion of the curve could be found for all thermocouples. A linear least-squares curve fit of $\ell n[(TT-TW_i)/(TT-TW)]$ versus time was applied to the data. The data were reduced starting at centerline to obtain a linear portion of the curve. The curve fit extended for a time span which was a function of the heating rate, as shown on the following list.

Range	Number of Points	Time Span, Sec
$DTW/DT > 32$	5	0.272
$16 < DTW/DT \leq 32$	7	0.408
$8 < DTW/DT \leq 16$	9	0.612
$4 < DTW/DT \leq 8$	13	0.884
$2 < DTW/DT \leq 4$	17	1.156
$1 < DTW/DT \leq 2$	25	1.700
$DTW/DT \leq 1$	41	2.788

In general, the time spans given above were adequate to keep the evaluation of the right-hand side of Eq. (2) within the linear region. The value of c was assumed to be 0.12 Btu/lbm-°F, based on thermal response data obtained prior to the test on a small sample of the surface plate material. The value of density was 487 lbm/ft^3, and the skin thickness, b, for each thermocouple is listed in Table 3.

The methods by which HWEDGE and TRT were calculated are discussed in Appendix III.

Data measurements obtained from the thermopile Gardon gages are gage ouput (E) and gage edge temperature (TGE). The gages are direct reading heat flux transducers and the gage output is converted to heating rate by means of a laboratory-calibrated scale factor (C1). The scale factor has been found to be a function of gage temperature and therefore must be corrected for gage temperature changes,

$$C2 = C1\ f(TGE) \tag{3}$$

Heat flux to the gage is then calculated for each data point by the following equation:

$$QDOT = (C2)(E) \tag{4}$$

The gage wall (surface) temperature used in computing the gage heat transfer coefficient is obtained from two measurements - the output of the gage edge thermocouple (TGE) and the temperature difference (TGDEL) from the gage center to its edge. The temperature difference is determined from the gage output and a laboratory-calibrated scale factor (KG) as follows:

$$TGDEL = (KG)(E) \tag{5}$$

The gage wall temperature is then computed as

$$TW = TGE + (0.75)(TGDEL) \tag{6}$$

where the factor 0.75 represents the average or integrated value across the gage.

A least-squares linear extrapolation method to QDOT = 0 was used to obtain model adiabatic wall temperature (TAW). Determination of TAW is important in Tunnel A where the difference between the model wall and recovery temperature is small. This small temperature difference causes the calculation of heat transfer coefficient to be sensitive to deviations from the actual recovery temperature. The data reduction procedure is based on the concept that

$$H(TAW) = \frac{QDOT}{TAW-TW} \tag{7}$$

where H(TAW) is assumed constant. Rearranging Eq. (7) gives

$$QDOT = [H(TAW)][TAW] - [H(TAW][TW] \tag{8}$$

where [H(TAW)][TAW] is a constant. Equation (8) can be written in the form of a straight line:

$$QDOT = A0 + A1(TW) \tag{9}$$

Since AO and A1 are constants, a comparison of Eqs. (8) and (9) gives

$$H(TAW) = -A1 \tag{10}$$

Setting QDOT = 0 in Eq. (9) and solving for TW leads to the following relationship:

$$TW_{(QDOT\,=\,0)} = TAW = \frac{-AO}{A1} \tag{11}$$

The actual steps in the data reduction procedure are to obtain a linear curve fit of QDOT versus TW for each gage and evaluate AO and A1 in Eq. (9). The quality of the curve fit is verified by examining the plotted data on a graphics display terminal. When the curve fit has been verified, the heat transfer coefficient can be calculated from Eq. (10) and the adiabatic wall temperature can be determined from Eq. (11). The value of TAW is checked to see if it is within the following range:

$$0.8 \leq \frac{TAW}{TT} \leq 1.01 \tag{12}$$

If Eq. (12) is not satisfied, an asterisk is printed next to the value of TAW in the tabulated data.

3.4 UNCERTAINTY OF MEASUREMENTS

In general, instrumentation calibrations and data uncertainty estimates were made using methods recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of bias and precision errors defined as:

$$U = \pm(B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution (95-percent confidence interval), which for sample sizes greater than 30 is taken equal to 2.

Estimates of the measured data uncertainties for this test are given in Table 1a. The data uncertainties for the measurements are determined from in-place calibrations through the data recording system and data reduction program.

Propagation of the bias and precision errors of measured data through the calculated data was made in accordance with Ref. 2 and the results are given in Table 1b.

4.0 DATA PACKAGE PRESENTATION

Sample data tabulations are presented in Appendix IV and the parameters are identified in the nomenclature.

It was found to be impossible to change data rates without stopping the data system. This resulted in runs 1 and 2 being obtained at the higher data rate for the entire run. Because of the large volume of data obtained, data for these two runs could not be reduced.

Runs 3 through 9 were obtained prior to remedying problems with the diagnostic plot capabilities. Once plots were available, it was clear that transitional flow was experienced over a significant portion of the instrumented wedge surface. In addition, the transition region moved forward as the wall temperature of the plate increased. Runs 10 through 17 were obtained with #60 grit trips on and therefore comprise the useful data from this entry.

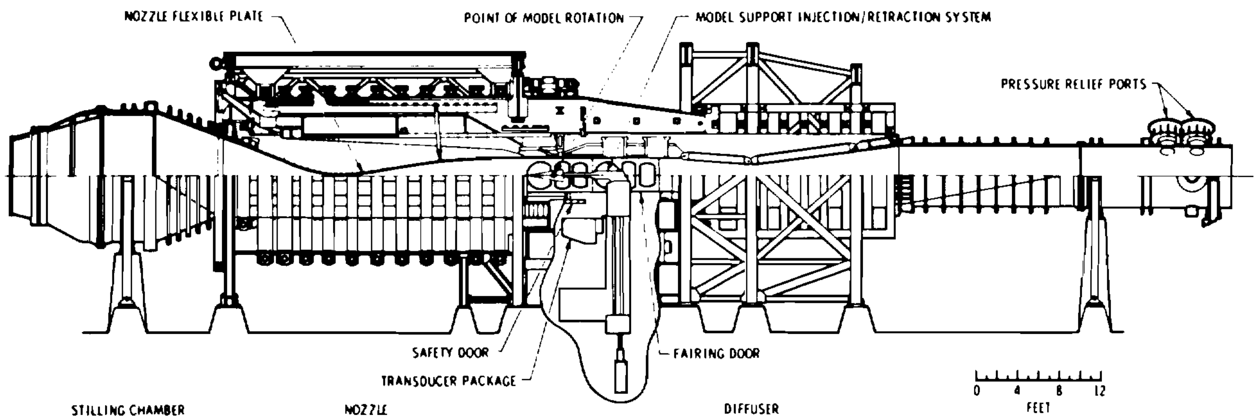
REFERENCES

1. Test Facilities Handbook. Eleventh Edition. "von Karman Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, June 1979.

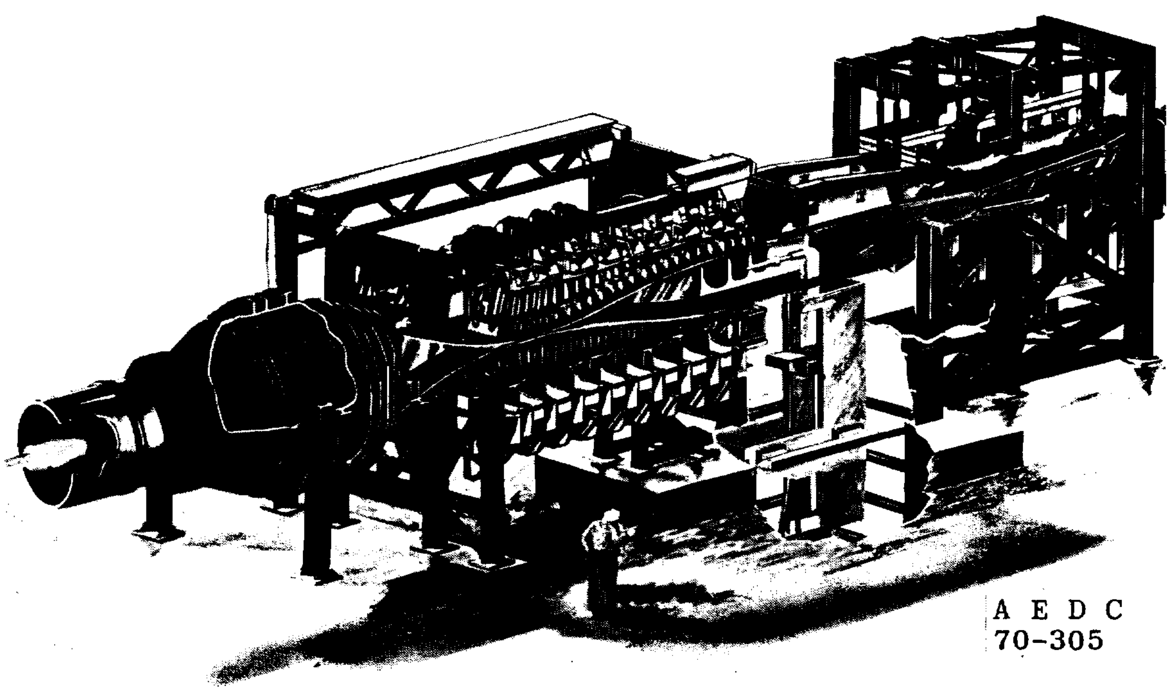
2. Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD-755356), February 1973.

APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section
Fig. 1 Tunnel A

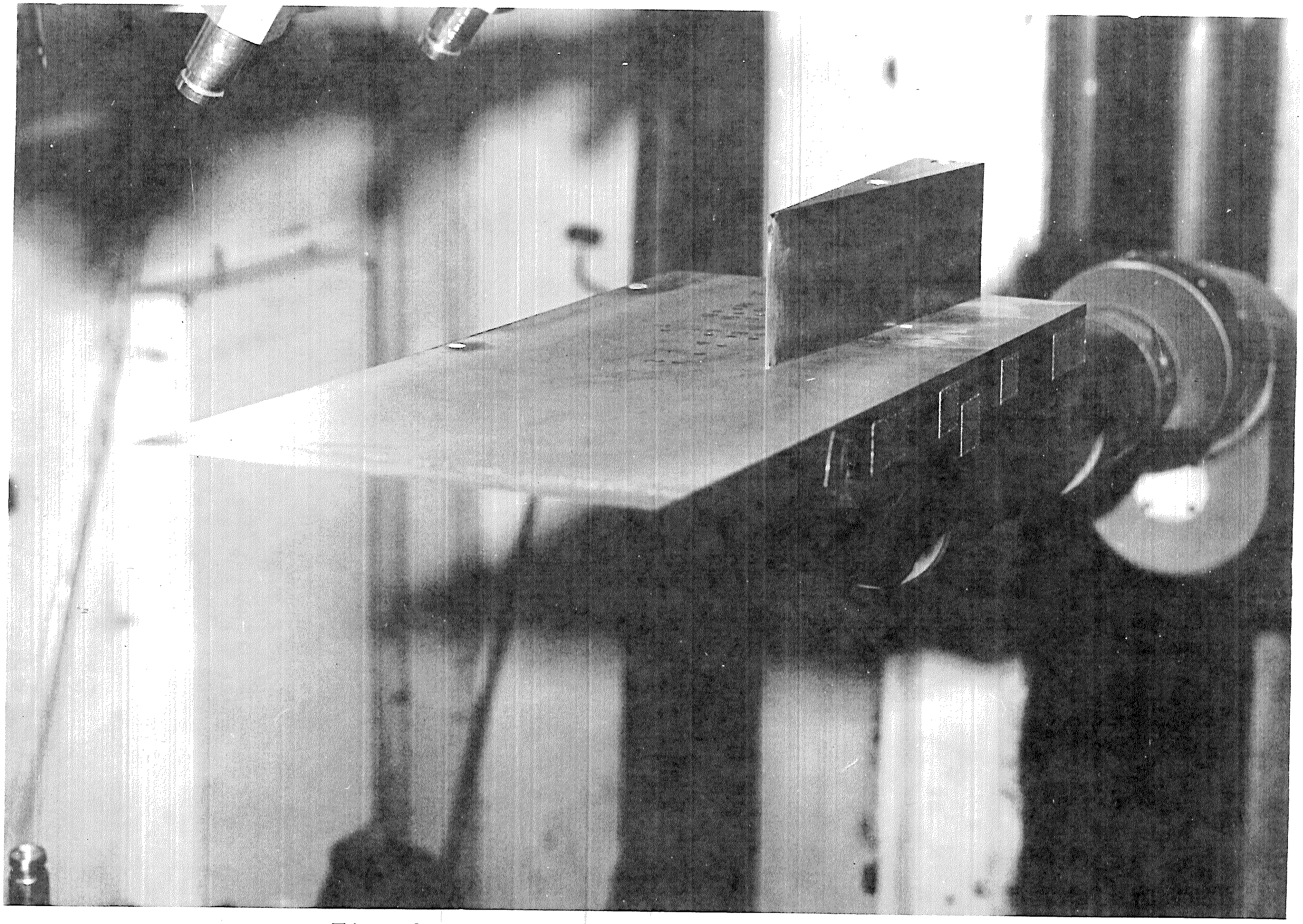
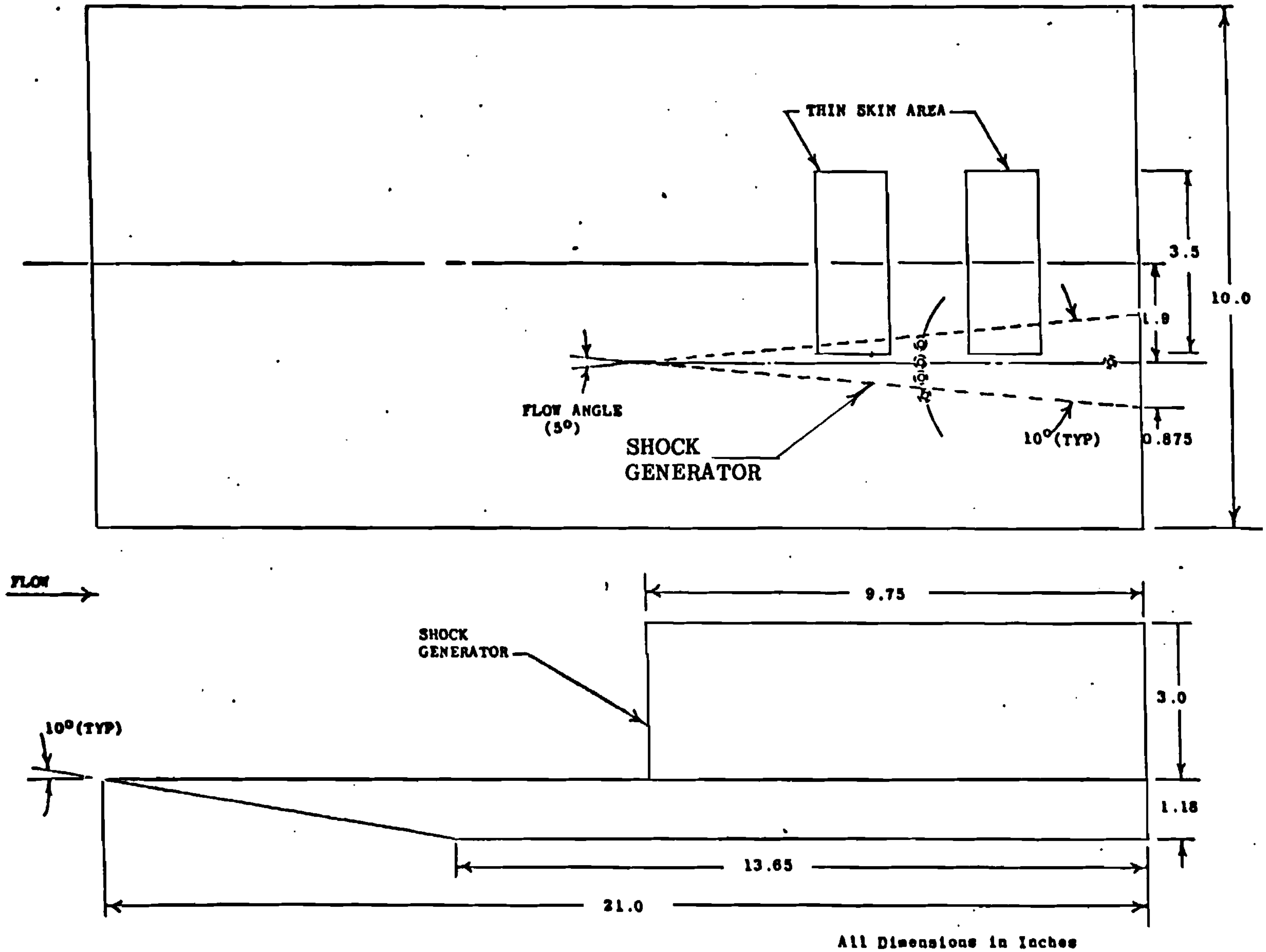
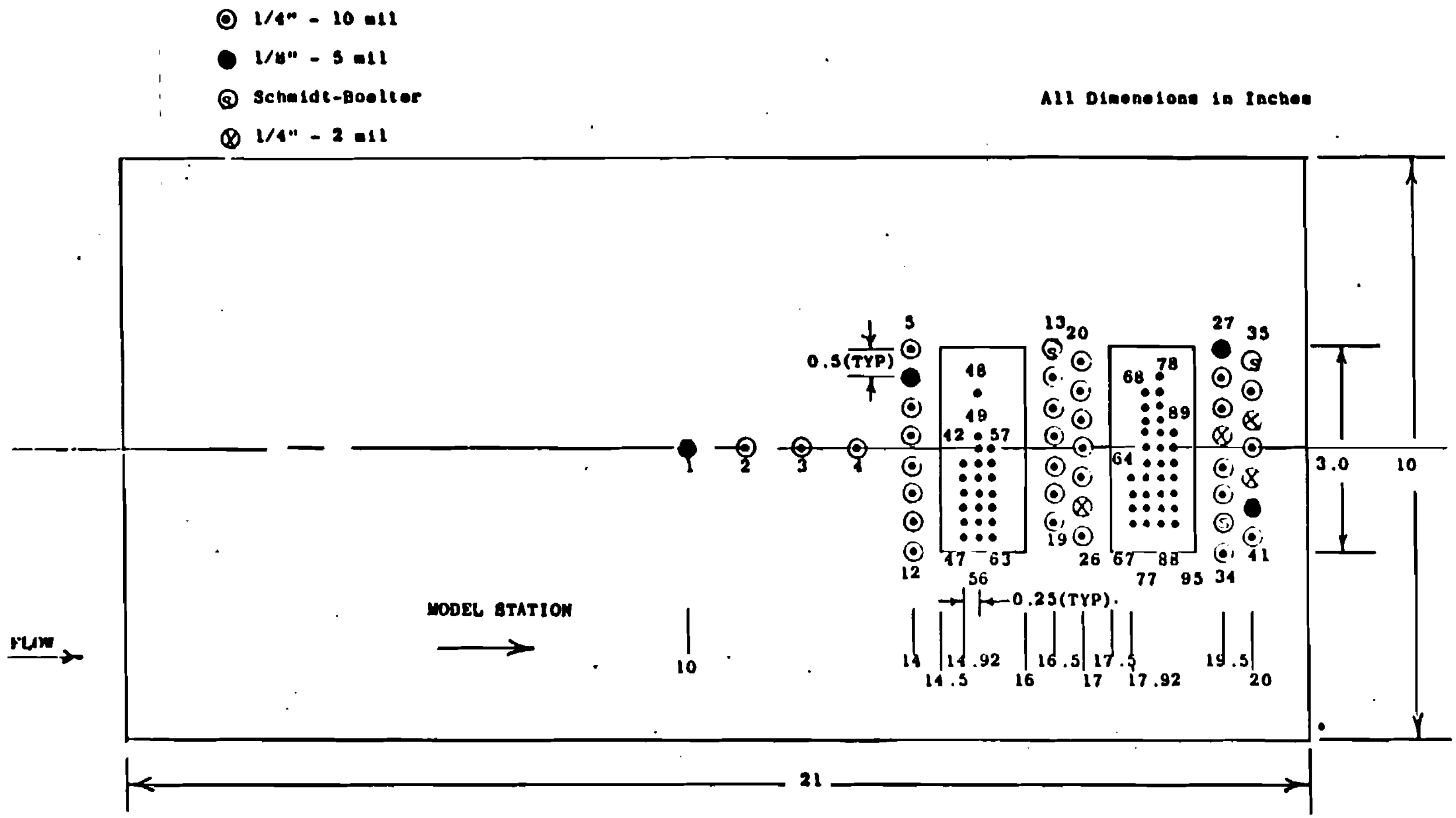


Fig. 2. Model Photograph - Front 3/4 View
with Shock Generator in Place



a. Surface Plate Details

Fig. 3. Model Details



b. Instrumentation Sketch

Fig. 3. Concluded

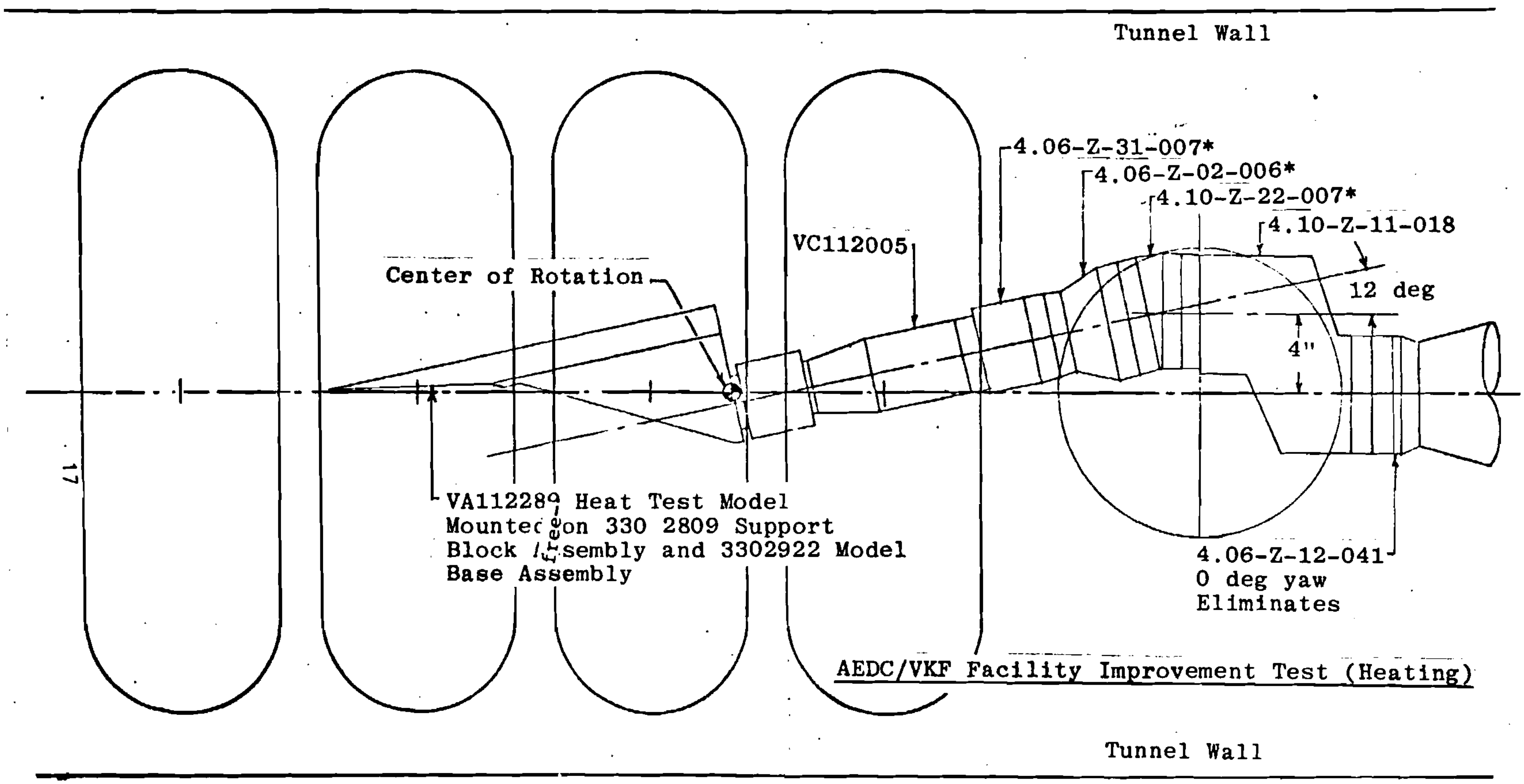


Figure 4. Installation Sketch

APPENDIX II

TABLES

TABLE 1. ESTIMATED UNCERTAINTIES

a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*							Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$					
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
c, BTU/lb_m-°F	0+			±5.0		±5.0					
PT, psia		±0.007	>30	±0 2		±(0.2% + 0.014)		60 psi	Bell and Howell force balance pressure transducer	Digital Data acquisition system analog-to-digital converter	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the Standards Laboratory
REFERENCE PRESSURE (PREF), microns		±25	>30	±10		±(10% + 50)		1000	Hastings vacuum gage	Digital data acquisition system/analog-to-digital converter	Comparison to facility reference gage
TIME CODE GENERATOR sec		$\pm 5\times10^{-4}$	>30	(Runtime(sec)x5×10^{-6}) ±		[(Runtime(sec)x5×10^{-6}) + 10^{-3}]		0 to 365 days	Systron Donner time code generator	Digital data acquisition system	Instrument lab calibration against Bureau of Standards
TT, °F		±1	>30		±2		±4	0-300°F	Chromel®-Alumel® thermocouple	Doric temperature instrument digital multiplexer	Thermocouple verification of NBS conformity/voltage substitution calib.
TW, °F (Fe-CN)		±1	>30		±2		±4	50 to 300	Fe-CN thermocouple	Beckman analog-to-digital converter	Voltage substitution calibration, secondary standard
RHO, lbm/in.^{3}	0+			±1.0		±1.0					
ALPI, deg		±0 025	>30		0+		±0.05	±15	Potentiometer	Digital data acquisition system analog-to-digital converter	Heidenhain rotary encoder ROD 700 Resolution: 0 0006° Overall accuracy: 0.001°
PHII, deg		±0.15	>30		0+		±0.3	±180			

*Thompson, J. W. and Abernethy, R. B. et al. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.
+Assumed to be zero

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TABLE 1. Concluded
b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S): Percent of Reading	Precision Index (S): Unit of Measure-ment	Precision Index (S): Degree of Freedom	Bias (B): Percent of Reading	Bias (B): Unit of Measure-ment	Uncertainty $\pm(B + t_{95}S)$: Percent of Reading	Uncertainty $\pm(B + t_{95}S)$: Unit of Measure-ment	Range
$d/dt \ln .(\frac{TT-TW_i}{TT-TW})$	±3.0		>30	±13.0		±19.0		All
PT2,psia	±0.69		>30	±0.20		±1.58		M=3.0
Q,psia	±0.67		>30	±0.20		±1 54		M=3.0
RE	±0.49		>30	±0.48		±1.46		M=3.0
M		±0.008	>30		0+		±0.016	M=3.0
ALPHA,deg		±1			0+		±2	All

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.
+Assumed to be zero

TABLE 2. Test Summary

Run	Surface Angle (deg)	Shock Generator	Boundary-Layer Trips	Comments
1	0	OFF	OFF	Data not reduced
2	12			" " "
3	25			
4	0			
5	12			
6	0			
7	0	5-DEG		
8	12			
9	25			
10	0	OFF	ON	
11	12			
12	25			
13	25			
14	0	5-DEG		
15	12			
16	25			
17	12.5	OFF		PHII = 180

* All data taken at same tunnel condition:

PT = 36 PSIA

TT = 700^{o}R

RE = 3.8×10^6 ft^{-1}

M = 3.0

TABLE 3

Thermocouple Location and Skin Thickness

T/C	X^* in.	Y^+ in.	b in.
42	14.92	0.25	0.052
43		0.50	
44		0.75	
45		1.00	
46		1.25	
47		1.50	
48	15.17	-1.00	
49		-0.25	
50		0.00	
51		0.25	
52		0.50	
53		0.75	
54		1.00	
55		1.25	
56		1.50	
57	15.42	0.00	
58		0.25	
59		0.50	
60		0.75	
61		1.00	
62		1.25	
63		1.50	
64	17.67	0.50	0.030
65		0.75	
66		1.00	
67		1.25	
68	17.92	-1.00	0.027

T/C	X^* in.	Y^+ in.	b in.
69	17.92	-0.75	0.027
70		-0.50	
71		-0 25	
72		0.00	
73		0.25	
74		0.50	
75		0.75	
76		1.00	
77		1.25	
78	18.17	-1.25	
79		-1.00	
80		-0.75	
81		-0.50	
82		-0.25	
83		0.00	
84		0.25	
85		0.50	
86		0.75	
87		1.00	
88		1.25	
89	18.42	-0.25	
90		0.00	
91		0.25	
92		0.50	
93		0.75	
94		1.00	
95		1.25	

* X measured from leading edge of surface plate, positive downstream

+ Y measured from centerline of plate, positive away from disturbance generator attachment location

APPENDIX III

TRT AND HWEDGE CALCULATIONS

WEDGE CONDITIONS

To calculate TRT (Theoretical Recovery Temperature) and HWEDGE (Wedge Heat Transfer Coefficient Calculated from Theory), local wedge flow conditions must be determined. To do this, the pertinent parameters from wedge tables have been curve-fit as a function of Θ_W (wedge surface angle) for various Mach numbers. The following procedure should be used.

1) Determine Θ_W:

   Θ_W = -ALPHA

   where ALPHA is model angle including deflection (determined from shadowgraph pictures).

2) Calculate three values for each of P_e/P, T_e/T, M_e from wedge table curve-fit equations.

APPENDIX III (Continued)

3) Linearly interpolate parameter values on free-stream Mach number to arrive at P_e/P, T_e/T, M_e.

4) From calculated free-stream conditions and #3 above, calculate wedge flow pressure (P_e), Temp (T_e) and Velocity (V_e)

$$P_e = (P_e/P)\, P \qquad \text{(psia)}$$

$$T_e = (T_e/T)\; T \qquad (°R)$$

$$V_e = (M_e)(49.0223) \quad T_e \qquad \text{(ft/sec)}$$

<u>TRT</u> (Recovery Temperature)

$$TRT = 0.9\;(TT - T_e) + T_e \qquad (°R)$$

NOTE: This temperature = $f(M, \Theta_w, T)$ only. (i.e. calculate once per run)

<u>HWEDGE</u>

To calculate heat transfer coefficient, the reference temperature must first be calculated:

$$T_n' = 0.5\left(TW_n + T_e\right) + 0.22\;(TRT - T_e) \qquad (°R)$$

where:

T_n' = Ref. Temp. for location #n (Gage or T.C.)

TW_n = Wall Temp. for location #n

Gages = $\bar{TW}$ at = 560°R

T.C. = TW at center of log-ratio fit

T_e = Local static temp. calculated above

TRT = Theoretical recovery temp. calculated above.

Finally:

$$HWEDGE_n = \frac{(8.1277 \times 10^{-4})(P_e V_e)^{0.8}}{(T_n')^{0.576}\; X_n^{\;0.2}}$$

APPENDIX III (Continued)

where:

P_e = Local Static Pressure From Above, psia

V_e = Local Flow Velocity From Above, ft/sec

$T_n{}'$ = Ref. Temp. for Location #n from above, °R

X_n = X value for location #n, in.

APPENDIX IV

SAMPLE TABULATED DATA

D, I DIW N

A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE

DATE COMPUTF 9-APR-80
TIME COMPUTF 10:34:02
DATE RECORDED 13-FEB-80
TIME RECORDED 2:34: 8
PROJECT NUMBER V41A-08

AEDC FACILITY IMPROVEMENT HEATING TEST

RUN	SHOCK	M	PT PSIA	TT DEGR	ALPPB DEG	ALPI DEG	PHII DEG	ALPHA DEG	WEDGE SURFACE ANGLE DEG
12	99	3.01	36.00	702.67	-12.00	-12.14	-0.10	-24.14	-25.00

T (DEGR)	P (PSIA)	Q (PSIA)	V (FT-SEC)	RHO (LBM/FT3)	MU (LB-SEC/FT2)	RE (FT-1)	TRT DEGR)
249.88	0.97	6.124	2333.	1.043E-02	1.999E-07	3.782E+06	676.5

- - - THIN SKIN DATA - - -

T/C	TW (DEGR)	DTW/DT (DEG/S)	QDOT (BTU/FT2-FT2-S)	H(TT) (BTU/FT2-SEC-DEGR	H(TAW) (BTU/FT2-SEC-DEGR)	HWEDGE (BTU/FT2-SEC-DEGR)	H(TT)/ HWEDGE	H(TAW)/ HWEDGE	X	Y	SKIN THICKNESS(IN)
42	535.5	7.006	1.804	1.0793E-02	1.2796E-02	1.7522E-02	0.61594	0.730	14.920	0.25	0.052
43	536.7	7.012	1.806	1.0880E-02	1.2917E-02	1.7511E-02	0.62134	0.738	14.920	0.50	0.052
44	537.4	6.736	1.735	1.0500E-02	1.2476E-02	1.7504E-02	0.59984	0.713	14.920	0.75	0.052
45	538.3	6.920	1.782	1.0842E-02	1.2895E-02	1.7496E-02	0.61968	0.737	14.920	1.00	0.052
46	539.8	6.978	1.797	1.0969E-02	1.3055E-02	1.7491E-02	0.62715	0.746	14.920	1.25	0.052
47	537.1	6.213	1.600	9.6645E-03	1.1479E-02	1.7507E-02	0.55203	0.656	14.920	1.50	0.052
48	530.3	7.575	1.951	1.1318E-02	1.3344E-02	1.7513E-02	0.64626	0.762	15.170	-1.00	0.052
49	532.2	7.641	1.968	1.1544E-02	1.3639E-02	1.7495E-02	0.65987	0.780	15.170	-0.25	0.052
50	532.3	7.666	1.975	1.1590E-02	1.3694E-02	1.7494E-02	0.66250	0.783	15.170	0.00	0.052
51	532.4	7.232	1.863	1.0941E-02	1.2928E-02	1.7493E-02	0.62544	0.739	15.170	0.25	0.052
52	534.1	7.396	1.905	1.1303E-02	1.3381E-02	1.7477E-02	0.64673	0.766	15.170	0.50	0.052
53	534.6	7.480	1.927	1.1461E-02	1.3575E-02	1.7473E-02	0.65596	0.777	15.170	0.75	0.052
54	535.7	7.428	1.913	1.1460E-02	1.3590E-02	1.7462E-02	0.65626	0.778	15.170	1.00	0.052
55	536.4	7.399	1.906	1.1461E-02	1.3602E-02	1.7456E-02	0.65656	0.779	15.170	1.25	0.052
56	535.5	6.509	1.676	1.0027E-02	1.1889E-02	1.7464E-02	0.57416	0.681	15.170	1.50	0.052
57	529.6	7.644	1.969	1.1374E-02	1.3400E-02	1.7462E-02	0.65133	0.767	15.420	0.00	0.052
58	530.2	7.456	1.920	1.1138E-02	1.3131E-02	1.7456E-02	0.63805	0.752	15.420	0.25	0.052
59	531.5	7.592	1.955	1.1421E-02	1.3482E-02	1.7445E-02	0.65468	0.773	15.420	0.50	0.052
60	532.8	7.320	1.885	1.1098E-02	1.3120E-02	1.7432E-02	0.63667	0.753	15.420	0.75	0.052
61	549.2	9.638	2.482	1.6180E-02	1.9508E-02	1.7281E-02	0.93629	1.129	15.420	1.00	0.052
62	534.1	7.539	1.942	1.1518E-02	1.3636E-02	1.7420E-02	0.66123	0.783	15.420	1.25	0.052
63	533.1	6.795	1.750	1.0323E-02	1.2208E-02	1.7429E-02	0.59227	0.700	15.420	1.50	0.052
64	541.7	7.678	1.141	7.0894E-03	8.4666E-03	1.6883E-02	0.41992	0.501	17.670	0.50	0.030
65	542.7	8.073	1.200	7.4976E-03	8.9643E-03	1.6875E-02	0.44431	0.531	17.670	0.75	0.030
66	542.5	8.176	1.215	7.5865E-03	9.0690E-03	1.6876E-02	0.44955	0.537	17.670	1.00	0.030
67	542.2	7.653	1.137	7.0876E-03	8.4694E-03	1.6879E-02	0.41991	0.502	17.670	1.25	0.030
68	545.5	9.802	1.311	8.3401E-03	1.0007E-02	1.6802E-02	0.49637	0.596	17.920	-1.00	0.027
69	546.2	9.543	1.276	8.1553E-03	9.7936E-03	1.6796E-02	0.48555	0.583	17.920	-0.75	0.027
70	546.8	9.465	1.266	8.1213E-03	9.7606E-03	1.6791E-02	0.48368	0.581	17.920	-0.50	0.027

a. Thin-skin Data

Sample 1 Sample Tabulated Data

O, [illegible] DIV[illegible]ON
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE

DATE COMPUTED [illegible]-APR-80
TIME COMPUTED 08:04:56
DATE RECORDED 13-FEB-80
TIME RECORDED 2:34:58
PROJECT NUMBER V41A-08

AEDC FACILITY IMPROVEMENT HEATING TEST

RUN	SHOCK	M	PT PSIA	TT DEGR	ALPPB DEG	ALPI DEG	PHII DEG	ALPHA DEG	WEDGE SURFACE ANGLE DEG
12	99	3.01	36.04	702.67	-12.00	-12.12	-0.10	-24.12	-25.00

T (DEGR)	P (PSIA)	Q (PSIA)	V (FT-SEC)	RHO (LBM/FT3)	MU (LB-SEC/FT2)	RE (FT-1)	TRT DEGR)
249.88	0.97	6.124	2333.	1.043E-02	1.999E-07	3.782E+06	676.5

- - - HEAT GAGE DATA - - -

GAGE	TAW	TAW/TT	TAW/TRT	H(TAW)	HWEDGE	H(TAW)/HWEDGE	X	Y
1	665.59	0.947	0.984	1.74954E-02	1.87740E-02	0.932	9.90	0.00
2	655.77	0.933	0.969	1.68817E-02	1.84160E-02	0.917	10.91	0.00
3	656.74	0.935	0.971	1.84788E-02	1.80954E-02	1.021	11.91	0.00
5	662.30	0.943	0.979	1.37715E-02	1.75421E-02	0.785	13.91	-1.75
6	670.06	0.954	0.990	1.93312E-02	1.75421E-02	1.102	13.91	-1.25
8	657.84	0.936	0.972	1.64937E-02	1.75421E-02	0.940	13.91	-0.25
9	664.76	0.946	0.983	1.44874E-02	1.75421E-02	0.826	13.91	0.25
10	661.92	0.942	0.978	1.62643E-02	1.75421E-02	0.927	13.91	0.75
11	663.29	0.944	0.980	1.46185E-02	1.75421E-02	0.833	13.91	1.25
12	665.16	0.947	0.983	1.30903E-02	1.75421E-02	0.746	13.91	1.75
13	658.17	0.937	0.973	1.38296E-02	1.69716E-02	0.815	16.41	-1.75
14	657.27	0.935	0.972	1.62159E-02	1.69716E-02	0.955	16.41	-1.25
16	658.21	0.937	0.973	1.74254E-02	1.69716E-02	1.027	16.41	-0.25
17	659.47	0.939	0.975	1.63018E-02	1.69716E-02	0.961	16.41	0.25
19	662.50	0.943	0.979	1.57624E-02	1.69716E-02	0.929	16.41	1.25
20	659.47	0.939	0.975	1.57141E-02	1.68700E-02	0.931	16.91	-1.50
21	658.79	0.938	0.974	1.54082E-02	1.68700E-02	0.913	16.91	-1.00
22	655.95	0.934	0.970	1.60742E-02	1.68700E-02	0.953	16.91	-0.50
24	662.63	0.943	0.980	1.59579E-02	1.68700E-02	0.946	16.91	0.50
25	673.42	0.958	0.995	1.30604E-02	1.68700E-02	0.774	16.91	1.00
26	658.33	0.937	0.973	1.67548E-02	1.68700E-02	0.993	16.91	1.50
27	663.01	0.944	0.980	1.95626E-02	1.64111E-02	1.192	19.41	-1.75
28	666.89	0.949	0.986	1.66216E-02	1.64111E-02	1.013	19.41	-1.25
29	664.11	0.945	0.982	1.53279E-02	1.64111E-02	0.934	19.41	-0.75
30	671.37	0.955	0.992	1.19938E-02	1.64111E-02	0.731	19.41	-0.25
32	665.07	0.946	0.983	1.76698E-02	1.64111E-02	1.077	19.41	0.75
33	663.63	0.944	0.981	1.35538E-02	1.64111E-02	0.826	19.41	1.25
34	669.39	0.953	0.990	1.41439E-02	1.64111E-02	0.862	19.41	1.75
35	679.18	0.967	1.004	1.68937E-02	1.63278E-02	1.035	19.91	-1.50
36	667.23	0.950	0.986	1.51344E-02	1.63278E-02	0.927	19.91	-1.00
37	680.75	0.969	1.006	9.02860E-03	1.63278E-02	0.553	19.91	-0.50
38	672.70	0.957	0.994	1.42675E-02	1.63278E-02	0.874	19.91	0.00
39	668.37	0.951	0.988	7.02947E-03	1.63278E-02	0.431	19.91	0.50
40	667.07	0.949	0.986	1.44531E-02	1.63278E-02	0.885	19.91	1.00
41	670.04	0.954	0.990	1.36046E-02	1.63278E-02	0.833	19.91	1.50

b. Heat Gage Data

Sample 1 Concluded